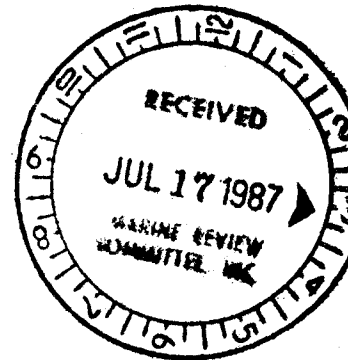


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VOLUME III  
STATISTICAL ANALYSES:  
ESTIMATED PHYSICAL CHANGES DUE TO SONGS

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We are submitting a revised version of Volume III-1 entitled "Statistical Analyses: Estimated Physical Changes Due to SONGS". In this revised version we have included Upstream-Downstream and BACI analyses on the logarithm of irradiance as well as BACI analysis on temperature and seston. This revision of Volume III does not take full account of all reviewers' comments received so far. This will be done in the complete draft to be submitted on September 30, 1987. The treatment of results in 1.5 with low significance levels is unsatisfactory and will be revised in the September draft.

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## STATISTICAL ANALYSES: ESTIMATED PHYSICAL CHANGES DUE TO SONGS

### 1.0 UPSTREAM-DOWNSTREAM ANALYSES

#### 1.1 INTRODUCTION

Beginning in late 1983, a number of stations with instruments to record currents, irradiance and temperature were installed in the vicinity of SONGS, at the locations shown in Figure 1-1-1, to implement a plume-monitoring program for the MRC. This program was specifically designed for the difficult task of looking for statistically-significant physical changes attributable to the operation of SONGS, separating them from the coherent natural changes and random fluctuations that largely dominate the histories of physical variables off San Onofre.

Since the opportunities to make comparison measurements at times when SONGS was not operating would be limited to occasional shutdowns after 1983, the program was designed to compare measurements at times when a station was in the plume of SONGS Units 2 and 3 with those at times when the station was not in the plume, by a scheme called Upstream-Downstream analysis.

Here the term "plume" means the body of water discharged and entrained by the SONGS diffusers within some chosen span of time preceding the time of measurement. The boundaries of the plume are

generally ill-defined, and it would certainly be very difficult, conceptually or practically, to determine with high accuracy that a given place is in or out of the plume at a given hour. For a feasible approximation, measurements were classified as in the plume (Plume) or out of the plume (Ambient) by applying a simple model for the behavior of the plume. The premises of this model are these: the advection of water in the plume is given by the current history recorded in the vicinity, with an added offshore velocity due to the original momentum of the discharge; the dispersion of water outward from the sides of the plume is given by Okubo's expression (1974) for the spreading of dye-patches in the sea. Using this model, the water at a station at a given hour is back-tracked by adding up displacements hour by hour until the back-trace crosses an operating diffuser line; the time elapsed since the most recent crossing is called the plume age of the water at the original place and time of a measurement. Measurements are classified as Plume or Ambient by whether the plume age is or is not less than a chosen cut-off age, which was taken as 10 hours in the analyses reported here. Details of this plume model are given below in 1.2.

Besides the plume model, these analyses also require a model for the nature of the SONGS effects and the natural effects that are to be separated from them. Consider two stations called N and S, one north of the diffusers and one south, and two sets of data, a set denoted by (0) from times when N was Ambient and S was Plume, and a set denoted by (1) from other times when N was Plume and S was Ambient.

$N_0$  PA Sp  
 $S_0$  PA Sp  
 $N_1$  PA Sp  
 $S_1$  PA Sp

$$\begin{aligned}
 N_0 &= I + A_N + E \\
 S_0 &= I + P_S + L + E \\
 N_1^{-2} &= I + P_N + C + E \\
 S_1 &= I + A_S + L + C + E
 \end{aligned}$$

Measurements of irradiance at the two stations and two sets of times are modelled linearly as:

$$N_0 = I + A_N + \varepsilon$$

$$N_1 = I + P_N + C + \varepsilon$$

$$S_0 = I + P_S + L + \varepsilon$$

$$S_1 = I + A_S + L + C + \varepsilon, \quad \text{in which}$$

$$N_0 - S_0 = A_N - P_S - L$$

$$N_1 - S_1 = P_N - A_S - L$$

$$(N_0 - S_0) - (N_1 - S_1) = (A_N - P_S) - (P_N - A_S)$$

$$N_1 - S_1 - (N_0 - S_0) = (P_N - P_S) - (A_N - A_S)$$

$$(N_1 - S_1) - (N_0 - S_0) = P_N - A_S = A_N + P_S$$

$$(P_N + P_S) - (A_N + A_S)$$

$$(P_N - A_N) + (P_S - A_S)$$

- I is a constant irradiance,
- $A_N$  is the added irradiance due to SONGS at the north station when this station is Ambient,
- $A_S$  is the same, at the south station,
- $P_N$  is the added irradiance due to SONGS at the north station when this station is Plume,
- $P_S$  is the same, at the south station,
- C is the natural difference between the times in the different sets (0) and (1), which may be due to the differences between currents at different times or to any other natural changes with time,
- L is the mean natural difference of irradiance between the ~~two~~ stations due to their different locations, and
- $\varepsilon$  is a random fluctuation averaging to zero.

As the equations show, the natural time-difference C is taken to be the same at both stations, and the natural location-difference L is taken to be constant over time. Both kinds of natural difference are potentially much too large to leave out of the model; what the model must assume is that there are no natural differences between times



(other than the fluctuations that average out) that are unequal at the two stations.

This is a system of four equations in seven unknowns, which cannot be solved for each of the unknowns. The partial solution that can be obtained by subtraction and averaging of the equations is:

$$\Delta \bar{A} = \bar{A}_1 - \bar{A}_0 = (\overline{N_1 - S_1}) - (\overline{N_0 - S_0}) = (P_N - A_N) + (P_S - A_S),$$

which is twice the average over the two stations of the SONGS-induced difference in irradiance between Plume and Ambient times.

$$\Delta \bar{A} / 2 = [(P_N - A_N) + (P_S - A_S)] / 2$$

This measure of SONGS' effects on irradiance is the best that can be obtained in the presence of large and unknown C and L, unless there also are enough data sets from times when SONGS was not operating, and with one station at a distance beyond the influence of SONGS, to provide four more equations (with one more unknown from the natural time difference between ON and OFF periods) so that the whole system can be solved to give P and A effects at the near station separately, instead of their difference.

$$\begin{aligned} F_0 &= I + M + \epsilon \\ F_1 &= I + M + C + \epsilon \end{aligned}$$

*6 m. 800 ft.*

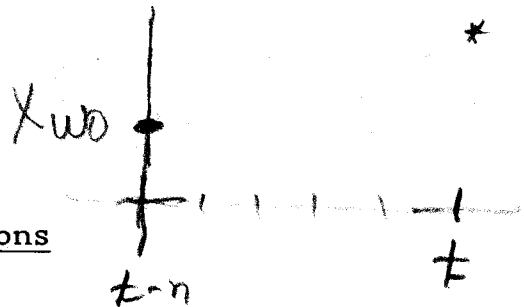
Some analyses of this kind are described in 1.5 below. The necessary assumption that there are no time changes acting unequally on the two stations becomes weaker with distance, though, and it seems likely that these ON/OFF analyses with a distant station do in fact strain this assumption.

Meanwhile it is most important to remember that the irradiance changes  $\Delta\bar{A}/2$  reported here are the estimated differences between Plume and Ambient times due to SONGS, averaged over both stations. These are not generally the same thing as the aggregate effect of SONGS over the whole period of observation, averaged over both stations. To relate the two requires further knowledge or assumptions about the separate P's and A's, and also about the effects of SONGS at the stations at times when neither station was in the plume.

*basically want to know  
P<sub>s</sub> - A<sub>w</sub> during periods critical  
to keep record intact*

Direct estimates of the aggregate SONGS effects at some stations are given by the BACI analyses reported in 2.0. These are derived by overall comparisons of long spans of time before and after SONGS began operation, so the results are only comparable with long-term averages of (P-A). A comparison of these BACI results with the overall Upstream-Downstream results from 1.6, leading to separate estimates for  $\bar{P}$  and  $\bar{A}$ , is given in the final section 3.0.

1.2 The Plume Model for Classifying Observations



The actual computations for classifying an observation made at the MRC coordinates (X, Y) and hour t as Plume or Ambient were done in the following steps by a program named PLUME.SAS.

The longshore coordinate  $X_W$  at  $t$  of water that left the diffusers  $n$  hours before  $t$  was computed as

$$X_W(t, n) = X_{W0} + \sum_{k=0}^n -V_{t-k\Delta t} \Delta t$$

$t$	$X(t)$
0	350
1	360
2	370
...	...
10	450

where V is hourly mean longshore current (m/hr, with positive V directed toward negative X) derived from local records as described later on;

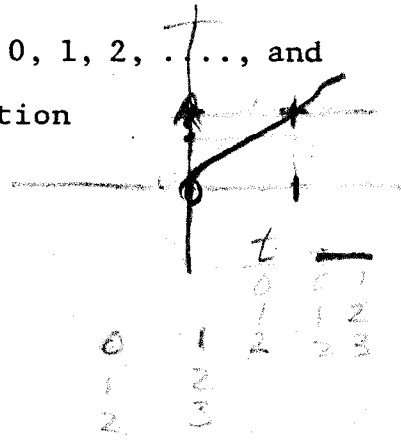
$\Delta t = 1$  hour, and  $X_{W0} = +350$  m, taken to be the MRC X-coordinate of both diffusers. For every hour t,  $X_W$  was computed for  $n = 0, 1, 2, \dots$ , and for each n the results were tested against the condition

$$X_{W0} < X(t) < X_{W1}$$

$$X_W(n, t) < X(t) < X_W(n+1, t) \text{ for } X > 0$$

or

$$X_W(n, t) > X(t) > X_W(n+1, t) \text{ for } X < 0.$$



If the condition was satisfied for n (meaning that water discharged in the nth hour before t crossed the X-coordinate of the station in the hour t), the cross-shelf coordinates  $Y_{WL}$  and  $Y_{WU}$  at t of water discharged at t-n from the inshore (L) and offshore (U) ends of the

operating diffusers were computed by the model

$$Y_{WL}(n,t) = Y_0 - \sigma + \sum_{k=0}^n (U_{t-n} + U_D) \Delta t$$

$$\text{and } Y_{WU}(n,t) = Y_{WL} + 2\sigma + L,$$

where  $Y_0$  is the MRC Y-coordinate of the inshore end of the most inshore operating diffuser (that is, Unit 3 if only Unit 3 is operating and Unit 2 if both or only Unit 2 are operating);  $U$  is hourly mean longshore current derived from records in the same way as  $V$  (m/hr; positive  $Y$  and  $U$  are directed onshore);  $U_D = -180$  m/hr, taken to be a constant additional offshore velocity imposed by the momentum of the discharge;  $\Delta t = 1$  hour, as for  $X_W$ ;  $L$  is the length of one diffuser if only one is operating, or the combined length of the two if both are operating; and  $\sigma = 10.8 n^{3/2}$  (m) is the standard deviation of distance of particles dispersing in the sea over  $n$  hours from the ends of the diffusers, derived from a relation given by Okubo (1974), discussed below.

As we said,  $Y_{WL}(n,t)$  and  $Y_{WU}(n,t)$  were computed for the first  $n$  that satisfied the condition on  $X$ . These were then tested against the condition  $Y_{WL}(n,t) > Y(t) > Y_{WU}(n,t)$  (all station  $Y$ 's are negative). If this condition on  $Y$  is also satisfied, besides the condition on  $X$ , it means that the station at  $(X,Y)$  at hour  $t$  lies within the boundaries of the part of the model plume that left the diffusers within hour  $t-n$ . At the smallest value of  $n$  for which both conditions were satisfied, the hour  $t$  was assigned a plume age of  $n$  hours, and the computations were started over for the next hour  $(t+1)$ .

When both conditions were not satisfied for  $n = 0, 1, 2, 3, \dots$ , the computations were cut off at a specified  $n$ , and no plume age was assigned to  $t$  at that location. At the final stage of actually classifying measurements as Plume or Ambient, a further cut-off was applied. In the analyses reported here, measurements at  $X, Y, t$  with plume age  $n < 10$  hours were classified as Plume, and those at  $x, y, t$  with  $n \geq 10$  hours, or with no assigned value, were classified as Ambient.

To produce a series of representative hourly values of ambient  $V$  and  $U$  for these computations, with as few data gaps as possible,  $V_t$  and  $U_t$  were formed by averaging the means for hour  $t$  from the records of several current meters at 3 m depth. The locations used for these averages in different years were:

1984: UVT08, UVT09, UVT10, UVT11  
1985: UVT01, UVT11, UVT12, UVT13  
      UVT14, UVT17, UVT18, UVT19  
1986: UVT13, UVT14, UVT17, UVT18

These locations are shown on the station map Figure 1-1-1; they are symmetrically disposed about SONGS. The stations of choice would be UVT 13, 14, 17, and 18, as in 1986, bracketing SONGS but probably not much influenced by plume velocities; the closer stations were used by necessity in earlier years because these stations were not yet installed. All stations on the list for a given year that were operating in hour  $t$  were included in the average for that hour.

180 m/hr = 18000 cm / 3600 sec = 5 cm/sec

The offshore velocity  $U_D = -180$  m/hr or  $-5$  cm/sec, chosen as a constant to represent the offshore momentum of the plume itself, was derived from inspection of dye-trajectories in a hydraulic scale-model of the SONGS diffusers (Koh, et al, 1974, Figures 6.3-6.7), with corroboration of its general magnitude from many field observations. The classification of hours as Plume or Ambient did not turn out to be very sensitive to moderate variations of  $U_D$ .

$$\sigma = (C_1 \epsilon)^{1/2} t^{3/2} = (2.5 \times 10^{-9} \text{ m}^2/\text{sec}^3)^{1/2} \times (3.6 \times 10^{-9} \text{ hr}^3)^{1/2} = 10.8 \text{ m/hr}^{3/2}$$

Okubo (1974) fitted a large body of data on dye-patches dispersing in the sea by the relation  $\sigma^2 = C_1 \epsilon t^3$ , with  $C_1 \epsilon = 2.5 \times 10^{-5} \text{ cm}^2/\text{sec}^3$  for times up to half a day. This gives  $\sigma = 10.8 n^{3/2}$ , in meters for  $n$  in hours, as the standard deviation of the distance of particles dispersing from a point, relative to their center of mass. This expression was used to represent dispersion of plume-water from points on the bounding trajectories given by the other terms in  $X_W$  and  $Y_W$ , essentially to express the fact that the plume grows wider with time.

These representations of the effects of plume momentum and dispersion are certainly inexact, but they come from arguments that have nothing to do with the data points being classified. The chosen cut-off time of  $n < 10$  hours is an arbitrary element, resulting from tuning the model in early trials, but the classifications are not strongly sensitive to small variations of the cut-off around 10 hours. At ages considerably larger than 10 hours, the condition on  $Y$  becomes easy to meet because of the growth of  $\sigma$ , and the conditions revert ultimately to a simpler criterion depending only on  $X$  and  $X_W$ .

$$\sigma = (C_1 \epsilon)^{1/2} t^{3/2}$$

$$2.5 \times 10^{-9} \text{ m}^2/\text{sec}^3$$
  

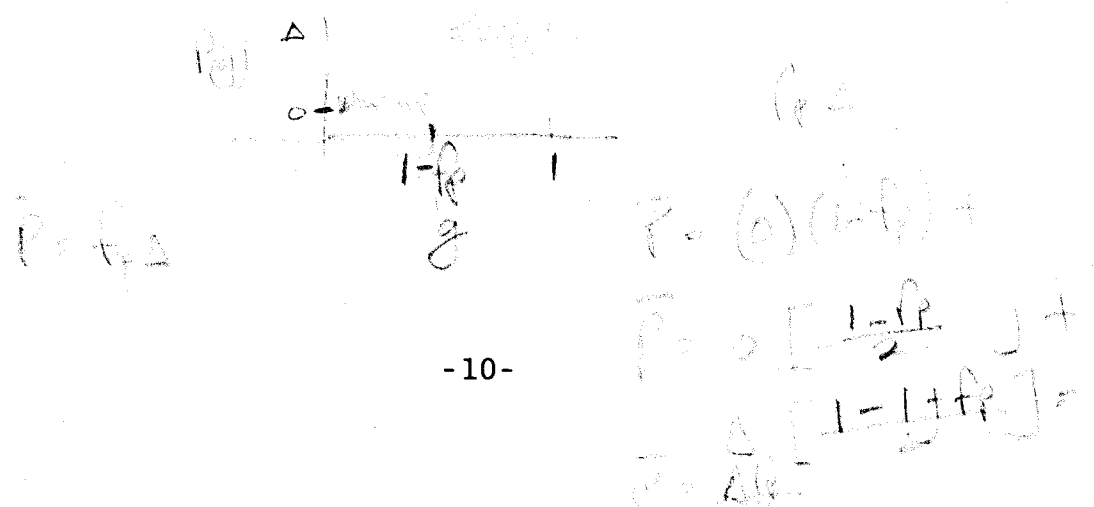
$$(2.5 \times 10^{-9} \text{ m}^2/\text{sec}^3)^{1/2} \times (3.6 \times 10^{-9} \text{ hr}^3)^{1/2} = 10.8 \text{ m/hr}^{3/2}$$
  

$$2.5 \times 10^{-6} \text{ cm}^2/\text{sec}^3$$
  

$$(2.5 \times 10^{-6} \text{ cm}^2/\text{sec}^3)^{1/2} \times (3.6 \times 10^{-9} \text{ hr}^3)^{1/2} = 10.8 \text{ cm/hr}^{3/2}$$

Actual plumes vary widely in dilution as well as location, and we should consider the effects of expressing plume influence as a dichotomy between present or absent. We can envisage an actual plume effect as  $P(g)$ , depending on the fraction  $g$  of plume-water (perhaps weighted by age) at a time and place. If we could measure  $g$ , we would probably look for  $P$  by a linear regression, modelling  $P(g)$  by  $Bg$  and  $\bar{P}$  by  $B\bar{g}$ . The dichotomy essentially models  $P(g)$  by a step-function, 0 for  $g$  between 0 and  $1-f_p$ , and  $\Delta$  for  $g$  between  $1-f_p$  and 1,  $f_p$  being the fraction of data points classified as Plume, and  $\Delta$  the difference of means between classes; the dichotomy models  $\bar{P}$  by  $f_p \Delta$ . An ideal dichotomy would give  $f_p = \bar{g}$  for any data set, and would be equivalent to a linear regression, giving  $b = \Delta$ . The minimum requirement for an acceptable dichotomy is that it should give  $f_p$  non-decreasing with  $\bar{g}$  when applied to many data sets.

If the actual  $P(g)$  is reasonably linear, so as to be well-fitted by a linear regression model,  $\Delta$  will be reasonably independent of variations in the fraction  $f_p$  resulting from the use of stringent or lax criteria for classifying a point as Plume. A search for bias in the estimates of  $\bar{P}$  given by a particular classification-scheme must be directed to interactions of the scheme with non-linearities in the actual effect.



### 1.3 Statistical Methods

The data sets of hourly irradiance values that are compared in these analyses show a high degree of autocorrelation; the departure from the mean of a value (or a difference) at a given hour is not independent of the departures in previous hours. When autocorrelation is present in the data, ordinary least-squares estimates are not efficient: even with large samples, the standard error is underestimated and the significance of an estimated difference is overestimated (the value of  $p$  is too small).

The method adopted to find proper  $p$ -levels for estimates drawn from these data sets was to recast the model of the SONGS-induced and natural effects discussed above in 1.1 into a linear regression model with autocorrelated errors, as follows: taking the data sets denoted by (0) and (1) in 1.1 together, the irradiance difference (N-S) for a given hour  $t$  is expressed as  $N-S = \Delta(t) = B_0 + B_1W(t) + e(t)$ , with

$$e(t) = A_1e(t-1) + A_2e(t-2) + A_3e(t-3) + \varepsilon(t) .$$

In this expression,  $B_0$  and  $B_1$  are constants, and  $W(t)$  is an indicator variable that takes on the value 0 for hours in the data set (0), when S is classified as Plume and N as Ambient, and takes on the value 1 for hours in the data set (1), when N is called Plume and S Ambient. The north-south differences in the error terms in 1.1 are written as  $e(t)$ , a sum of previous error differences, each multiplied by a constant coefficient  $A_n$  for its lag of  $n$  hours, plus a final term  $\varepsilon(t)$  representing independent normal errors.



Apart from the treatment of error terms, this regression model is equivalent to the model 1.1, and the physical assumptions about the nature of SONGS-induced and natural changes are exactly the same. The average over all the hours with  $W=0$  gives  $B_0 = N_0 - S_0 = A_N - P_S - L$ ; the average over all the hours with  $W = 1$  gives  $B_0 + B_1 = N_1 - S_1 = P_N - A_S - L$ ; and the difference of the two averages gives  $B_1 = (P_N - A_N) + (P_S - A_S) = \Delta\bar{\Delta}$  in the notation of 1.1. The natural current-effect or time-effect  $C$  is eliminated at the outset in this model by starting with the differences of paired observations at the north and south stations in the same hour.

The necessity, and the value, of the regression model comes from its ability to estimate each of the constants  $B_0$ ,  $B_1$ ,  $A_1$ ,  $A_2$ , and  $A_3$  in the presence of all the others, and to test each one separately for significant departure from zero.

The actual regression analyses were carried out by the SAS procedure PROC AUTOREG (SAS/ETS User's Guide, 1984, pp. 189-195), using the option of maximum-likelihood estimation strongly recommended by the Guide for data sets with many missing values. This SAS routine provides estimates of each constant, with its standard error, t-value, and p-value. The routine also provides, among other things, the total  $r^2$  (the fraction of the variance of  $\Delta(t)$  that is explained by the model), as a check that the model is actually suitable to the data sets.

As a preliminary to these analyses, the means and variances of hourly station differences in a number of data sets were computed for a

succession of three-day periods extending over six weeks; these three-day means were examined for trends against time and against each other. No such trends were found in many trials, and we have assumed that all the data sets used in these analyses are stationary time-series, as is required for the valid use of a regression model with no secular term proportional to time. A large set of trial runs also showed that the coefficient  $A_3$  was small and insignificant enough to be disregarded, and this term was dropped from the model. The important question of additivity in the data sets is treated in 1.6 below, and again in 2.1, in the discussion of BACI analyses.

As a final step, the residuals from the model were examined. There were occasional very large outliers, out to 9 standard deviations from zero, and a good number at 3 or 4 standard deviations, indicating that the residuals are not generally normal. We have taken no further steps to deal with these.

#### 1.4 Results of Upstream-Downstream Analysis of Irradiance

Each of Figures 1-1-2 through 1-1-12 gives plots of four variables throughout a year at one station. The uppermost plot is simply the daily mean irradiance recorded at the station, in  $E/m^2$ -day. The second plot gives an estimate every seventh day of  $\Delta\bar{\Delta}/2$  at the station, from analysis of a period of 28 days centered around the day in  $E/m^2$ -hr. The third and fourth plots give the fractions  $f_p$  of daylight hours (defined as hours with recorded  $I > .01 E/m^2$ -hr) and of all hours that were classified as Plume by the model given in 1.2. This distinction is necessary in studying relations between  $f_p$  and  $\Delta\bar{\Delta}/2$  because the plume of course does not affect irradiance in the absence of sunlight.

Since  $\Delta\bar{\Delta}/2$  is an average over many daylight hours, it can be approximately converted to  $E/m^2$ -day for comparison with the plot of mean daily irradiance simply by multiplying  $\Delta\bar{\Delta}/2$  by 10, which is about the average number of daylight hours (as defined here) per day in the data sets.

Recall that  $\Delta\bar{\Delta}/2$  plotted for a station is actually the average of P-A over the station and a counterpart on the other side of the diffuser lines. Whenever possible, the counterpart station was chosen to be at the same water depth and distance from the diffusers as the station it matched. Other stations were used as counterparts when it was necessary to fill data gaps, in the following orders of preference: in 1984, PS1 was the counterpart of choice for all the stations in SOK, with L45 as a

second choice; in 1985 and 1986, counterparts were chosen by the table below.

STATION	COUNTERPART		
	1	2	3
SOKU45 and SOKD45	PL45	PN	PIN
SOKU35	PN	PIN	PL45
SOKD35	PIN	PN	PL45

The locations of all these are shown in Figure 1.

The plots of  $\Delta\bar{\Delta}/2$  in Figures 2 through 12 show a nearly continuous history of negative P-A , a reduction of irradiance in Plume hours relative to Ambient hours at all four stations in SOK and their counterparts. This effect is on the order of  $-0.06 \text{ E/m}^2\text{-hr}$  , sometimes two or three times larger, and is mostly found at a significance-level of  $p \leq .05$  . Here it is worth reiterating that the model which leads to these results eliminates any consistent natural changes C due to correlation of irradiance with current-direction, say, so that the effect (P-A) must be attributed to something that lies between the station and its counterpart. This point is discussed further in 1.6.

### 1.5 Upstream-Downstream-On-Off Analyses

During 1984 and 1985 there were five periods of 15 to 35 days in which both of SONGS Units 2 and 3 were out of operation, to the extent that no heat was generated and the pumping rate for both units together was half or less of the rate for full operation. There were no such periods in 1986.

By comparing data from these OFF periods with data from adjacent periods of full operation, and using a distant station for the north station, we can set up a model like that in 1.1 to give a fully soluble system of eight equations in six unknowns. Denoting the data sets from OFF periods by primes, these equations are:

$$\begin{array}{ll} N_0 = I + \epsilon & N_0' = I + T + \epsilon \\ N_1 = I + C + \epsilon & N_1' = I + C + T + \epsilon \\ S_0 = I + P_S + L + \epsilon & S_0' = I + L + T + \epsilon \\ S_1 = I + A_S + L + C + \epsilon & S_1' = I + L + C + T + \epsilon \end{array}$$

The unprimed equations are those of 1.1, with  $P_N$  and  $A_N$  set equal to zero because the north station is distant from SONGS. All the notation is the same as in 1.1, except that a new constant  $T$  appears in the primed equations, expressing a natural difference between the ON and OFF periods which is taken to be the same at both stations. These equations give  $P_S = (S_0 - S_0') - (N_0 - N_0')$  and  $A_S = (S_1 - S_1') - (N_1 - N_1')$ , even if we relax the assumption that the natural current-effect  $C$  is the same at both stations.

The equivalent model used in the statistical analyses to deal with autocorrelated errors is a recasting of this model like that described in 1.3, now using three indicator variables to distinguish among the eight data sets. That is,

$$\Delta(t) = N-S = b_0 + b_1F + b_2G + b_3H + e(T) ,$$

in which F, G, and H are indicator variables taking on the values zero or one according to the following table.

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	F	G	H
SONGS OFF, S AMBIENT	0	0	0
SONGS OFF, S PLUME	1	0	0
SONGS ON, S AMBIENT	0	1	0
SONGS ON, S PLUME	0	0	1

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In this form of the model,  $-b_2$  is the estimate of  $A_S$ , the mean SONGS effect on the south station in hours when it is classified as Ambient;  $-b_3$  is the estimate of  $P_S$ , the mean SONGS effect on the south station in hours when it is classified as Plume. If the assumption that the natural change  $T$  is the same at both stations does not hold, then  $-b_2$  estimates  $A_S + (T_N - T_S)$  and  $-b_3$  estimates  $P_S + (T_N - T_S)$ ; that is, the same unknown error is added to the estimates of  $A_S$  and  $P_S$ . The discussion of statistical methods in 1.3 applies equally to this model and its application, since the only difference between the models is in the number of indicator variables.

The available OFF periods were:

JAN	13-FEB	11, 1984	,	30 days;
JUN	16-JUN	30, 1984	,	15 days;
OCT	28-DEC	1, 1984	,	35 days;
JAN	26-MAR	1, 1985	,	35 days;
NOV	16-DEC	1, 1985	,	15 days;

Corresponding ON data sets were formed by bracketing each OFF period of days with about half as many ON days or more from immediately before and after. So far as data were available, comparisons were made for each of the five periods; for each of the stations SOKD45, SOKD35, SOKU45, and SOKU35, each at two levels, on the bottom and 2 m above bottom; and using each of the stations SMK45, PMRN, PMRS, and BK55 at the corresponding level for the control station (which need not actually be north of SONGS or the other station).

There were enough data to run 55 of all these combinations. Of these runs, 28 gave no estimates of either  $P_S$  or  $A_S$  with  $p < .33$ , and in general were not considered further. The OFF period 16-30 June, 1984, for which only SMK45 was available as a control, gave significant large positive estimates of  $A_S$ :  $+.18 \text{ E/m}^2\text{-hr}$  ( $p = .015$ ) at SOKD45;  $+.23$  ( $p = .015$ ) at SOKD45;  $+.23$  ( $p=.016$ ) at SOKD35,  $+.11$  ( $p=.10$ ) at SOKU45, all at the level 0 m off bottom. The corresponding estimates at 2 m above the bottom were definitely not significant:  $-.04$  ( $p = .52$ ) at SOKD45,  $+.19$  ( $p = .38$ ) at SOKD35, and  $+.10$  ( $p = .71$ ) at SOKU45. The irradiance records for June and July of 1984 (see VI-3) show two large individual

peaks of irradiance within the OFF period occurring at both levels at SMK45; at the stations in SOK these peaks were less strong at 2 m above bottom and weak or absent at the bottom. The estimated positive  $A_S$  appears to be due to a relative suppression of irradiance at SOK in a special subset of the OFF days, rather than an enhancement at SOK in ON days; on these grounds, it is easier to accept this effect as a  $(T_N - T_S)$  arising from the failure of an assumption than to take it as an effect of SONGS on the SOK stations when SONGS is operating and the stations are not in the plume.

All the other estimates of  $A_S$  with  $p < .33$  averaged to  $+ .024 \text{ E/m}^2\text{-hr}$ ; 13 were positive and six negative. Estimates of  $P_S$  with  $p < .33$  averaged  $-.032 \text{ E/m}^2\text{-hr}$ ; 7 were negative and 1 positive. Taking only the estimates with  $p < .10$ , the estimates of  $A_S$  averaged  $+.037$  (6 positive, 3 negative) and the estimates of  $P_S$  averaged  $-.049$  (6, all negative).

Only five runs gave estimates of both  $P_S$  and  $A_S$  from the same data sets with one having  $p < .10$  and the other having  $p > .33$ . The results from these (with p-levels in parentheses) are:

$P_S$	$A_S$
-.014 (.32)	-.024 (.09)
-.014 (.19)	-.019 (.08)
-.035 (.04)	-.027 (.13)
-.039 (.09)	-.071 (.18)
-.080 (.10)	-.044 (.21)

*Handwritten notes:*  
 I  
 SOK  
 ↓  
 Bk  
 Bk



The first three of these pairs are from the same location and period (SOKU 45 at the bottom, Jan.-Feb. '84) with different controls (SMK, PMRS, BK, in order). The other two are from other and different places and periods, with BK as the common control.

In contrast to the Upstream-Downstream analyses of close station-pairs in 1.2, which produced a three-year month-by-month calendar of consistently negative estimates for P-A, mostly significant at the level  $p < .05$ , the Upstream-Downstream-On-Off analyses do not lead to any conclusive results unless one refuses to discount the results of June-July 1984.

## 1.6 Overall Upstream-Downstream Analyses of Irradiance and the Logarithm of Irradiance

The results given in 1.4 above show smoothed histories of (P-A) at four stations in SOK. In this section, the data for each station in the separate years 1985 and 1986 are combined to estimate the average for the station and year. These analyses have been carried out for the irradiance  $I$ , and also for its natural logarithm  $\ln I$ . To show the reason for this, and to interpret the results, we must consider the assumptions of the model in 1.1 more closely, from the point of view of the additivity of the data sets.

It was noted in 1.1 that the model must assume that natural changes between times in state (0) and times in state (1) are the same at both stations. That is, the mean natural difference between stations, after averaging out random fluctuations, must be constant over time, and the same for both states. This assumption is certainly not true in general for any variable that may be studied. To use the linear or additive model on a particular data set, this assumption must be validated by statistical testing of the data set, with or without the support of physical arguments about how the data is expected to behave.

The problem is most simply illustrated by considering a Before-After-Control-Impact study (see 2.0 below) to detect and estimate a powerplant effect on the abundance of some organism, though the principles are the same for the more complex Upstream-Downstream